Vol. 94 (1998) *ACTA PHYSICA POLONICA A* No. 3

Proc. of the XXVII Intern. School on Physics of Semiconducting Compounds, Jaszowiec 1998

DEEP LEVEL STUDIES IN $Zn_{1-x}Mg_xSe$ LAYERS GROWN BY MBE

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The deep levels present in semiconducting $Zn_{1-x}Mg_xSe$ ($0 \leq x \leq 0.4$) were investigated by means of deep level transient spectroscopy, photocapacitance transient and thermally stimulated depolarization. The thermal activation energy levels estimated from the deep level transient spectroscopy measurements are: $E_{T1} = 0.28$ eV and $E_{T2} = 0.56$ eV. For the $Zn_{1-x}Mg_xSe$ epilayers thermally stimulated depolarization curves consist of four overlapping peaks: 227.4 K, 243.6 K, 265.7 K, and 285.0 K.

PACS numbers: 71.55.Eq, 72.80.Ey

1. Introduction

The $Zn_{1-x}Mg_xSe$ ternary compounds have been suggested in the last years as attractive material for various optoelectronic devices, especially for blue emitting diodes and lasers [1–3]. However, the lifetime of ZnSe laser diodes under continuous wave operation is too short for commercial applications. The degradation of these diodes has been ascribed to the propagation of crystal defects during the growth. In order to reduce the density of defects in the $Zn_{1-x}Mg_xSe$/GaAs heterostructures ($0 \leq x \leq 0.4$), it is of crucial importance to obtain a detailed understanding of the electrical and optical properties of these materials [4]. The investigation of deep levels in these heterostructures is thus necessary to understand their electrical and optical properties, in particular whether their high resistivity is achieved by a compensation process. In particular, there is rather little known about deep levels introduced into the $Zn_{1-x}Mg_xSe$ lattice by various doping procedures and different dopant species [5].

The aim of this work is to identify and characterize the deep levels present in the $Zn_{1-x}Mg_xSe$/GaAs heterostructures. Electrical measurements including current voltage (I–V), capacitance voltage (C–V), deep level transient spectroscopy (DLTS), photocapacitance transient (PCT), and thermally stimulated depolarization (TSD) were used to characterize electrical properties and deep levels in these heterostructures grown by MBE.

2. Experimental details

The $Zn_{1-x}Mg_xSe$ epilayers were grown on n^+ GaAs (001) substrates by solid source MBE in facility described elsewhere [6]. The source materials were metallic Zn (6N), Se (6N) and Mg (3N). The Schottky diodes ($Au/Zn_{1-x}Mg_xSe/GaAs/In$) were fabricated by evaporating Au dots 0.8 mm in diameter onto the $Zn_{1-x}Mg_xSe$ epilayers, and the ohmic contacts to the GaAs substrates were formed by alloying In. The structures were polarized with a constant electric field E_P ($0 \leq E \leq 1.5 \times 10^4$) V cm^{-1} for $t = 10$ min at room temperature and then cooled down to the temperature $T_0 = 90$ K after which the field was switched off. The structures were then heated up at a nearly constant rate (about 0.5 K s^{-1}).

The lock-in deep level spectrometer (DLS-81) was used for the DLTS and C–V experiment. The TSD currents were measured with electrometer (410 Keithley) (the noise level of our electric circuit was 5×10^{-16} A).

3. Results and discussion

Typical DLTS spectra obtained at different voltage biases applied to the $Au/Zn_{1-x}Mg_xSe/GaAs/In$ structure during cooling are shown in Fig. 1. The ap-

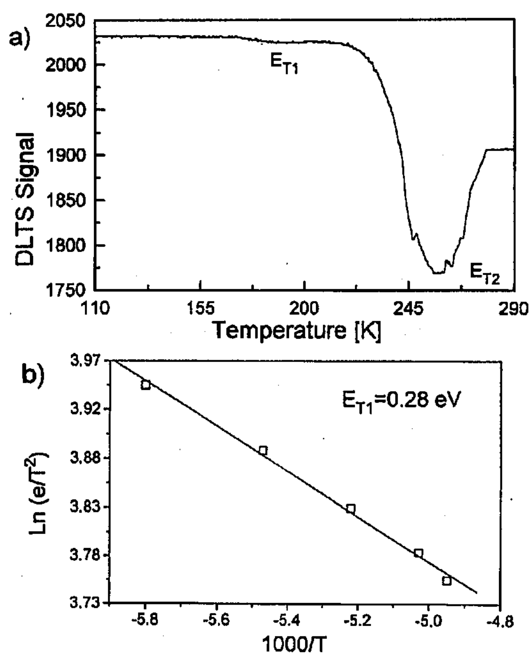

Fig. 1. Typical DLTS signal (in arbitrary units) of $Zn_{0.97}Mg_{0.03}Se$ layers grown on GaAs (a); parameters of DLTS measurements: reverse bias polarization, $U_r = 4$ V; forward bias polarization, $U_f = 4$ V; the width of the filling pulse, $T_d = 50$ μs. The Arrhenius plot for the trap observed in $Zn_{0.97}Mg_{0.03}Se$ layers grown on GaAs. The solid line results from least squares fits to the data (b).

plied voltage under temperature decrease was constant and changed at different measurements from the reverse ($U_C = 8$ V) to the forward bias ($U_C = -0.5$ V).

The increase in the pulse amplitude for a fixed reverse bias voltage broadens the DLTS peak and shifts its position toward lower temperatures. Similar behaviour of DLTS peaks for ZnSe:Cl/GaAs layers was observed by Karczewski et al. [5]. This behaviour can be explained by assuming a spatial variation of the electron emission rate due to the Poole–Frenkel effect [5, 7]. For all peaks the Arrhenius plots have been constructed (Fig. 1b). The resulting Arrhenius plots show a good exponential dependence of emission rates on inverse temperature. The thermal activation energy levels estimated from these measurements are: $E_{T1} = 0.28$ eV and $E_{T2} = 0.56$ eV.

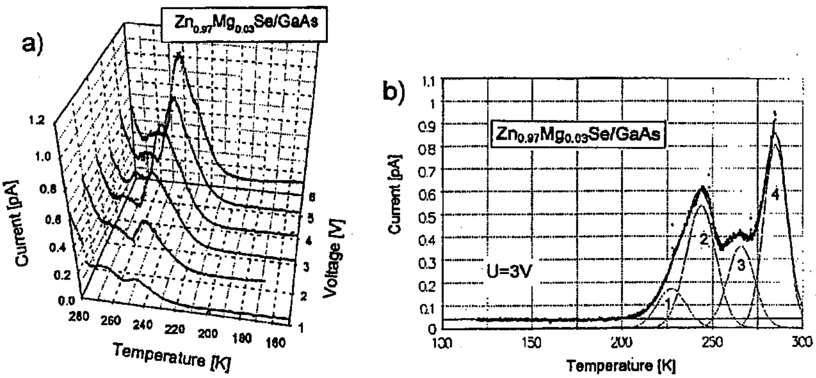

Fig. 2. The TSD spectra of $Zn_{0.97}Mg_{0.03}Se$ layers grown on GaAs, polarized at different electric field E_p; $t_p = 10$ min at room temperature (a). Fitting Gaussian functions for typical TSD spectra, polarized at $U_r = 3$ V (b). Number 1: 227.4 K, 2: 243.6 K, 3: 265.7 K, 4: 285.0 K.

Figure 2a shows the TSD current vs. temperature spectra obtained from the Au/$Zn_{0.97}Mg_{0.03}Se$/GaAs/In structure at different polarization. The curves consist of four overlapping peaks, labeled 1 (227.4 K), 2 (243.6 K), 3 (265.7 K), and 4 (285.0 K) (Fig. 2b). For bigger electrical fields E_P peaks overlay forming one broad band. The dominant one occurs at $T_{max} = 285.0$ K. The experimental determination of the thermal activation energies and capture cross-sections of these traps, which are in the same energy range as the trap E_{T2} (0.51–0.53 eV) [5], is rather complicated and needs further investigation.

The DLTS measurement reveals that when ZnSe is directly grown on a GaAs substrate, there exist five electron traps at thermal activation energies of 0.20, 0.23, 0.25, 0.37, and 0.53 eV, respectively [3–5, 7].

The lattice-matching may reduce the incorporation of different traps implying that these traps are ascribed to surface treatment of GaAs substrate and to lattice relaxation. Concentration of trap 0.37 eV is proportional to the donor concentration. However, in the $Zn_{1-x}Mg_xSe$/GaAs heterostructures, another trap level locates at the almost same position as that of trap 0.37 eV, and it shows anomalous behaviour, namely, the DLTS peak amplitude changes drastically on changing the rate windows.

This can be explained by the defect generation through the interaction between Mg and a GaAs substrate surface or through lattice mismatch. For the trap 0.20, the concentration is a function of donor concentration and lattice mismatch, and the origin is attributed to a complex of donor induced defects and dislocations.

4. Conclusions

The DLTS measurements reveal that when ZnSe is directly grown on a GaAs substrate, there exist five electron traps having the thermal activation energies of 0.20, 0.23, 0.25, 0.37, and 0.53 eV, respectively. The lattice-matching may reduce the concentration of different traps implying that these traps are ascribed to surface treatment of GaAs substrate and to lattice relaxation. The concentration of trap 0.37 eV is proportional to the donor concentration. However, in the $Zn_{1-x}Mg_xSe$/GaAs heterostructures, another trap level locates at the almost same position as that of trap 0.37 eV, and it shows anomalous behaviour that the DLTS peak amplitude changes drastically on changing the rate windows.

We correlated the DLTS spectra with the other spectra (TSD, PCT) to identify the defect-related transitions near the $Zn_{1-x}Mg_xSe$/GaAs interface, where the origins of the defects are yet uncertain and need further investigations [8].

Acknowledgment

This work was supported in part by the Committee for Scientific Research grant No. 2P03B 100 14 and grant No. 2P03B 055 14.

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